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AT

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CHAPTER XVIII

DOOR-BOATS(*)

Dry docks whose entrance lock is not equipped with miter gates are closed either by door-boats or by caissons capable of rolling on the dock bottom. The first solution is used exclusively in France and the United States; it is also frequently encountered in England, notably in one of the Portsmouth docks, at Blackwall near London, at Barry Dock and at Cardiff (Bute Dock); the second has been adopted for several Portsmouth docks, at Esquimalt, at Garvel Dock (Greenock) and at Montevideo. The caissons used in docks are identical to those used for closing navigation locks, so there is no need to return to these devices.

A door-boat is a removable watertight screen, capable of floating to clear the passage it closes, and which can be sunk in place by the introduction of water ballast; its lower and lateral surfaces then bear on a *sill* and on two *rabbets* located in the same plane. The door-boat is brought into the lock and beached before the dock is drained; it is raised after filling, the water ballast used to sink it having been previously removed.

The use of door-boats has various advantages: the closure is watertight due to the interposition of an *oakum gasket*, which is nailed onto the wooden rubbing pieces lining the *keel* and the *stem and stern posts*; maintenance is easy, the symmetrical shape allowing each of the two faces to be placed alternately on the dock side, where they can then be easily scraped and repainted; the presence of mud or foreign bodies on the lower sill of the lock does not present the same disadvantages for raising the door-boat as for the rotation of miter gates. On the other hand, the rabbets intended to receive the door-boats take up much less length than the gate chamber, hence a reduction in the total length of the structure. A door-boat can be placed indifferently in two or three different grooves, whereas a pair of miter gates can only serve one specific location. Finally, since a door-boat rests directly by its keel on the lower sill, it is easy to arrange it so that the upper deck can give passage to the heaviest loads.

On the other hand, the maneuvering of a door-boat is slower and more delicate than that of miter gates and requires more personnel; it can even be dangerous, if one is in a space where the sea is rough; finally, it requires that a garage berth for the door-boat be available near the passage. These disadvantages make the use of these devices unsuitable for closing navigation locks, but they are of little gravity for the locks of dry docks, given the time required for the entry and exit of ships and the personnel that must be on hand to perform these operations.

Door-boats were first made of wood, but this method of construction has the disadvantage of requiring great widths; moreover, the wood, by becoming soaked, changes weight and modifies operating conditions; finally, the walls, which are alternately wetted in the basin and dry in the dock, are in unfavorable conditions from

(*) The indications of figures in italics refer to them at the bottom of the document in order not to overload the text unnecessarily.

the point of view of their preservation. Therefore, for many years, all door-boats have been built exclusively of iron or steel.

The shapes given to door-boats are very variable: some, like that of Blackwall, consist of a rectangular parallelepiped; others have hulls similar to those of boats, such as those of docks 1, 2, 3 and 4 in Le Havre, Devonport, Kowloon Dock, etc.; others, like those of docks 5 and 6 in Le Havre, have straight shapes over their entire extent, connecting by simple curves with the stem/stern posts and the keel; finally, others, like those of the Calais and North German Lloyd docks in Bremerhaven, consist of a solid screen supported by a float.

The current trend is to simplify shapes as much as possible in order to make construction more economical and maintenance easier.

Door-boats are often used to re-establish communication between the two banks of the entrance lock; for this purpose, either a simple footbridge or a real bridge with a carriageway is provided at their upper part.

Whatever system is adopted, door-boats have air chambers and water chambers, containing permanent ballast or maneuvering ballast, and must satisfy a certain number of general conditions, namely:

1° Possess sufficient floating stability;

2° Be able to operate when the sea is at its lowest level at which ships can enter or leave the dock;

3° Provide a watertight closure;

4° Be easy to maintain.

RABBET

The rabbet must have such a shape that the door-boat clears easily; clearance is achieved either by ascent or by rotation. In any case, the keel of the door-boat must rise sufficiently to be at least 0.30 m above the lock sill, and the stem and stern posts must come out of the grooves on which they bear by 0.25 m to 0.35 m. Since the grooves in the lock sill are most often 0.50 m deep, the height to which the door-boat must rise is then at least 0.80 m to 1 m.

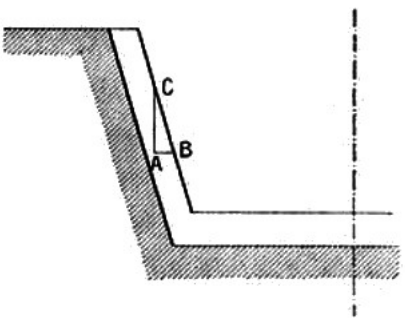


Fig. 603.

When the door-boat clears by a vertical upward movement (fig. 603), the inclination of the side walls must be such:

$$\frac{AB}{AC} = \frac{0.20\ m \text{ to } 0.35\ m}{0.80\ m \text{ to } 1.00\ m}$$

that the ratio is about 1/3 to 1/4, i.e., 1 base for 3 to 4 height. Indeed, this inclination was adopted in many older docks; it is now more rarely used, however in the Dunkirk docks the slope of the lock side wall is still about 1/3.

This arrangement has the disadvantage of greatly increasing the width of the upper part of the lock and consequently the length and weight of the upper parts of the door-boat. Therefore, it is generally preferred to give the side walls a smaller inclination and to clear the door-boat by pivoting it in the lock, turning around one of its ends (fig. 604); the rabbet is then flared. In this case, the side walls can be vertical, but in practice they are most often given a slight batter.

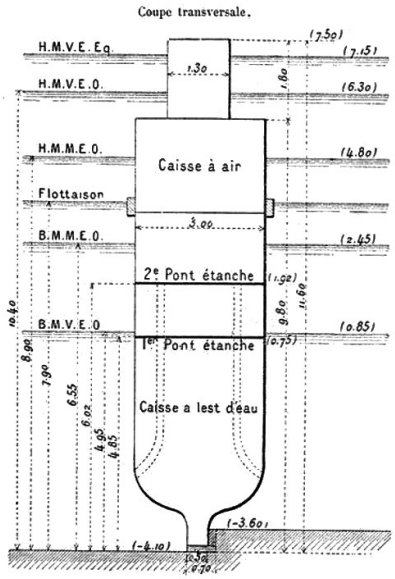
The grooves are vertical at Calais, Bordeaux and La Pallice; they have a batter of about 1/2.5 at Marseille, 1/3 at Dunkirk, 1/5 at Toulon, 1/6 at Cherbourg, 1/7 at Lorient and 1/8 at Le Havre. At Saint-Nazaire, the vertical grooves in the upper part have a slope of 1/1.7 in the lower part.

Door-boats of certain types, when beached, completely lose their floating stability at a given moment; they then tend to fall over on one side or the other. The rabbet in which the door-boat slides opposes this overturning; but if it is too wide, the door-boat must be held vertical during immersion by means of mooring lines attached both to its head and to its foot. This circumstance occurs notably at Lorient.

The dimensions of the rabbets vary with the shape of the stem and stern posts and the rubbing pieces with which they are lined.

VARIOUS TYPES OF DOOR-BOATS(*)

The door-boats of docks 1, 2, 3, 4 and 6 of the port of Cherbourg, executed according to the plans of Mr. Corrard, Naval Engineer, operate in a basin where the tide moves freely with an amplitude which, at spring tide, can exceed 7 m.



These door-boats (fig. 605) are divided in height into three compartments separated by watertight decks, the highest of which is called the rebate deck. The lower compartment is a water ballast tank, which is filled up to the deck that limits it to obtain the normal flotation of the door-boat; the middle compartment can also be filled with water, when it is desired to delay the raising of the door-boat. In other words, the water ballast fills only the lower compartment or both lower compartments, depending on whether the movement of the door-boat is to be carried out at one level or another of the tide. The upper compartment, or float, can be placed in communication at will either with the basin or with the dock.

These latter compartments are provided with bottom valves which are operated from the service deck located slightly above the level of ordinary spring high tides; they are usually left in free communication with each other through manholes made in the watertight decks, which are kept open for this purpose.

(*) Extract from a report written by Mr. Inspector General Henri Bernard on behalf of a commission of the General Council of Bridges and Roads.

The side walls are vertical below the rebate deck and connect with the keel by surfaces of double curvature. The upper part above the rebate deck is symmetrically reduced to a width of 1.30 m, in order to make the door-boat lighter in the upper parts. The top of the door-boat forms a footbridge.

Operation is very simple: when the lock is closed, water enters freely into the interior of the door-boat and reaches the same level as outside. When it is desired to make the door-boat float, it is allowed to fill with water only up to the level of that one of the two watertight decks which corresponds to the desired moment of flotation. Care is taken to fill the dock with water so as to establish the outside level before mid-tide; the door-boat floats when the water, rising freely inside and outside the dock, exceeds the level of the watertight deck by the desired height. Similarly, to put the door-boat back in place, it is brought into its grooves before mid-tide in such a way that it beaches solely by the lowering of the sea level. It can also be sunk immediately by letting water into the upper compartments.

The level of the first watertight deck, which is generally used, is calculated so that the door-boat rises at mid-tide, which gives about six hours to carry out the exit and entry of ships. The second watertight deck is placed so that the raising occurs one and a half hours later.

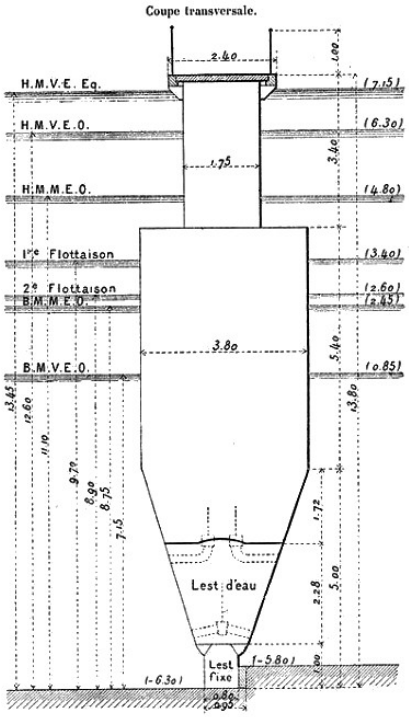


Fig. 606. — Cherbourg (bateau-porte de la forme 5).

These door-boats, except for one which is smaller, have a width of 3 m, a length of 17.60 m at the keel, 21.45 m at the top and a height of 11.60 m; the sill is at elevation (-3.60 m) and the abutment sill has a height of 0.80 m.

Dock 5 having been enlarged and its sill lowered to elevation (-5.80 m), a door-boat was built which has a width of 3.80 m, a length of 26 m at the keel, 30.60 m at the top and a total height of 13.80 m (fig. 606). But so that the door-boat, in case of repair, could enter docks with a higher sill, it was necessary to reduce the draft without destroying stability, which was achieved by substituting weight stability for form stability by means of cast iron and cement ballast placed as low as possible. The weight of the hull is 375 t, which with 165 t of fixed ballast gives 540 t displacement for the lower flotation and 605.6 t, with the 65.6 t of liquid ballast to be added for normal flotation. As a result of these arrangements, the door-boat, despite its great height, has only one watertight deck between the rebate deck and the keel, corresponding to the level above the liquid ballast.

In a tideless sea or in a floating basin, a door-boat of this system would rise as soon as the buoyancy of the water introduced into the dock, together with the external buoyancy, gave an upward pressure greater than the weight of the door-boat, increased by its adhesion to the masonry; this raising movement would occur most often before the level is the same in the dock and outside. Consequently, there would be a risk of

accidents occurring under the influence of the pressure differences resulting at that moment from the difference in level between the dock and the basin.

Mr. de Coppier, Naval Engineer, then studied, in 1858, another type of door-boat which was first applied to dock 1 of Castigneau at Toulon, and which since then has been reproduced many times both in tideless ports and in tidal ports.

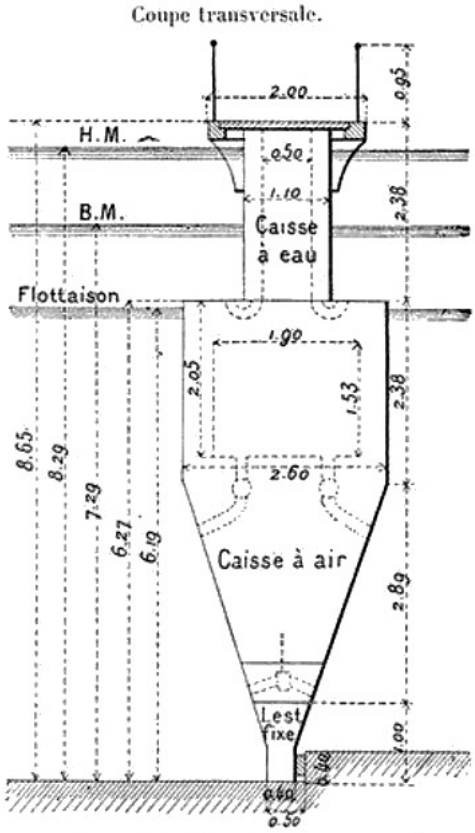


Fig. 607. — Toulon (bateau-porte de la forme 3 de la darse Vauban).

The door-boat (fig. 607) is divided in height into three parts. The lower compartment contains the permanent ballast, usually consisting of cast iron and concrete, and sometimes also of water ballast. The second compartment, or air chamber, intended to make the door-boat float, contains inside it one or two watertight water ballast tanks, the purpose of which is to serve for immersion or emersion depending on whether they are filled or emptied; the air escapes through tubes passing through the upper compartment. The latter, which forms a water chamber, is reduced to the width necessary for strength and communicates widely either with the basin or with the dock through orifices located in the lower part and provided with bottom valves or sluices, which are operated from the upper deck.

Normal flotation must be established at a height such that the distance separating it from the low water level, when the door-boat is beached, is slightly greater than the vertical height that the door-boat must travel to clear its grooves. This flotation is regulated by means of the permanent ballast, and the watertight deck, which separates the water chamber from the air chamber, is placed only a few centimeters above this flotation. It is then sufficient that the water chamber contained in the second compartment has a capacity slightly greater than the displacement of the small section of the door-boat between the second watertight deck and the normal flotation.

The door-boat is sunk by filling the water ballast tanks contained in the middle compartment, the bottom valves of the upper compartment being closed on the dock side and open on the basin side.

To make the door-boat float, all the bottom valves of the upper compartment are closed during the previous high tide, then the water from the water ballast tank is allowed to flow into the empty dock. The dock is then filled and, as soon as the water reaches a level very close to that of the basin, the door-boat rises slightly, without, however, its keel rising above the sill; the dock then finishes filling quickly, water entering it through the grooves.

To complete the emersion of the door-boat, it is sufficient to open the bottom valves of the upper compartment, the water of which flows out gradually, until the door-boat

has regained its normal flotation; the speed of emersion can be regulated by the greater or lesser opening of the bottom valves.

This door-boat system has the advantage of allowing, when necessary, the moment of raising to be delayed by increasing the normal draft; this increase is only temporary and it is easy to return to the normal draft as soon as the water level in the dock is approximately the same as outside. This advantage is valuable in tidal ports, if one wishes to avoid that the time available for maneuvers is reduced both by the later raising of the door-boat and by the necessity of bringing it before the abutment sill earlier after the entry of the ship.

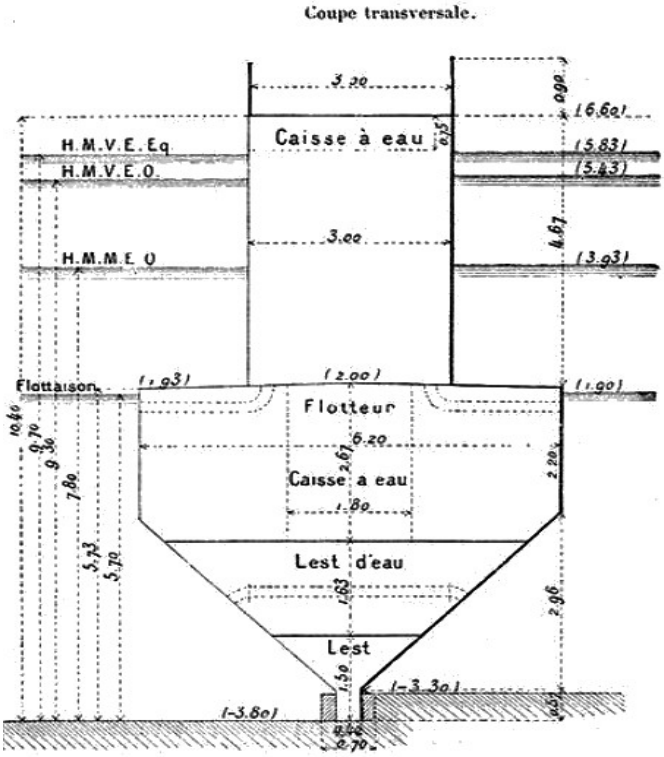


Fig. 608. — Saint-Nazaire (bateau-porte de la forme 1).

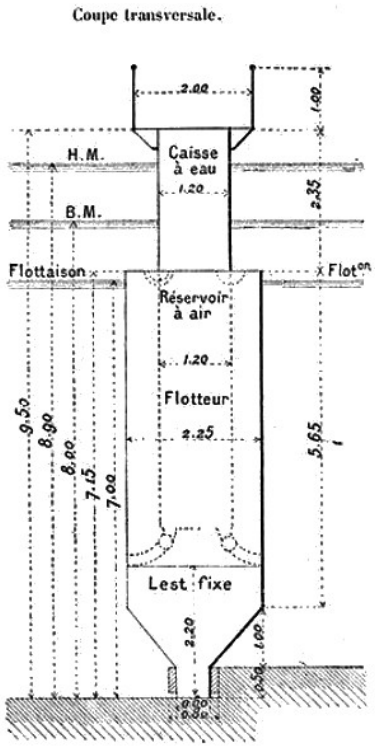


Fig. 609. — Marseille (bateau-porte de la forme 1.)

The door-boats of the Castigneau, Missiessy and Vauban docks at Toulon, and those of docks 2 at Lorient, Saint-Nazaire and Marseille belong to this type.

In the Saint-Nazaire door-boats (fig. 608), the upper water chamber is located above the high water level; it therefore fills, not freely by opening the valves, but by means of pumps which allow the water ballast contained in the lower water chamber to be raised into this chamber.

The door-boats of the six dry docks of Marseille (fig. 609) have the particularity that the bottom of the air chamber is not limited by a watertight deck, the fixed ballast being composed solely of cast iron and concrete placed above the keel.

The door-boats of the Le Havre docks also have only two compartments separated by a watertight deck. In addition, the water ballast tank below this watertight deck has been eliminated.

The door-boats of docks 2 and 3 of the citadel are provided at their upper part, above the highest water level, with a watertight tank which is intended to receive the water

necessary to sink them; this water is supplied by the city water distribution system; the lower part below the watertight deck forming the float contains the fixed ballast and must always be dry; the upper part can be kept empty or placed in communication with the basin. The ballast is regulated so that the door-boats float at the level of the watertight deck.

To sink these door-boats, the valves connecting the upper compartment to the basin are opened and the upper water chamber is filled; under the action of this overload, the door-boat begins to sink, and the water then entering the upper compartment soon causes it to beach. To make it float, the water from the tank is drained after the upper compartment has been emptied into the dock. The door-boats can therefore be sunk and raised at will without pumping.

But for some time, these upper water chambers have been discontinued, which were never even used for door-boat 1, which was also provided with them. They were not installed on the door-boats of docks 5 and 6.

In fact, the maneuvering of the Le Havre door-boats is carried out in the following manner:

For docks 1, 2, 3 and 4, the door-boat is brought afloat against its rabbets, then the valves of the watertight compartments on the basin side are opened as well as the bottom valves; water enters the lower part of the door-boat, which first sinks slowly, then more quickly when the watertight deck has fallen below the outside water level. The door-boat is generally raised only after the dock has been emptied for ship repair. Before filling the dock, the water contained in the door-boat is drained into it, leaving, however, a greater or lesser quantity depending on whether the water level in the basin is higher or lower.

Thus, the same waterline is not maintained; on the contrary, the aim is to ensure that the door-boat always rises by approximately the same amount, about 1 m. It can also be said that the quantity of water ballast that must remain in the door-boat is regulated so that the latter rises only when the difference in level between the basin and the dock does not exceed 0.30 m or 0.40 m at most. Under these conditions, emersion does not occur suddenly, but in two or three stages; the gaskets do not suffer and the filling of the dock is not completed quickly enough to cause the slightest inconvenience to the ship inside.

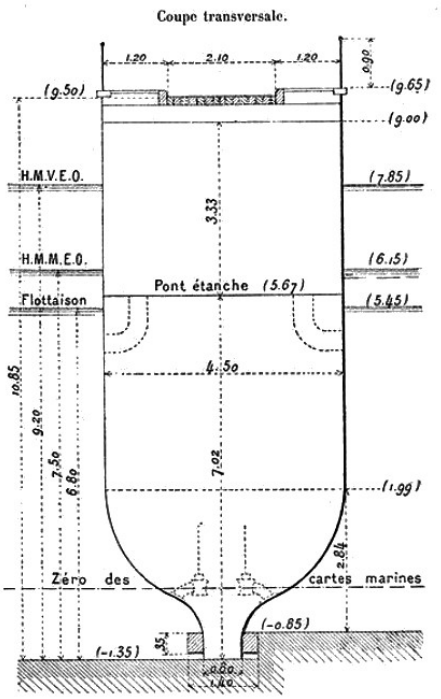


Fig. 610. — Le Havre (bateau-porte de la forme 5).

For the door-boats of docks 5 (fig. 610) and 6, it seemed useless to raise the valves of the upper compartment, since the bottom valves of the lower compartment have sufficient orifices to sink the door-boat quickly enough; water is therefore never introduced above the watertight deck.

When the door-boat must be raised while the dock is full of water, it is necessary to empty the door-boat by means of a pump or a pulsometer; but this is an exceptional case. It is obvious, moreover, that the same could be done with the four older door-boats.

Direct experiments were carried out to determine the height of water to be admitted into the lower compartment of door-boats 5 and 6 according to the different water levels in the Eure basin, so that the door-boats rise under good conditions; they gave the following results:

WATER LEVEL in the Eure basin	LEVELS AT WHICH WATER must be kept below the upper deck		HEIGHT to which the door-boat rises
	Door-boat 5.	Door-boat 6.	
Below 6.25 m .	11 m (door-boat empty)	10.15 m (door-boat empty)	Varies from 0.25 m to 1 m
6.50	9.30	8.15	
7.00	8.25	7.55	
7.50	7.85	7.00	
8.00	7.30	6.50	

From the above, it follows that the intermediate deck does not need to be watertight and that its position could be determined independently of flotation conditions; it could even be eliminated, which is what was done at Dunkirk (fig. 611).

The door-boats then become true caissons with vertical walls which are sunk or raised by the introduction or removal of additional water ballast, variable according to the desired flotation. Water is introduced by means of bottom valves and removed by letting the water flow into the drained dock. When the raising operation must be carried out without the dock having been emptied, it is necessary to resort to pumping either by means of pulsometers or by means of ordinary pumps driven by steam engines or by hand.In this port, it was necessary to reduce as much as possible the width of the door-boat of dock 4, in which the rudder well is only 1.20 m from the abutment sill; this door-boat is 2.50 m wide and supports cantilevered footwalks.

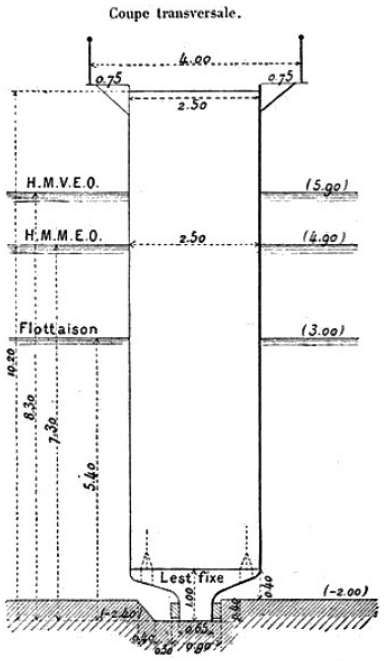


Fig 611. — Dunkerque (bateau-porte de la forme 4).

At Calais (fig. 612), the door-boat consists of a sheet metal diaphragm and an air chamber symmetrical with respect to this diaphragm, rising 0.20 m above the normal flotation. At the upper part, over a length of 13.75 m, there is in the middle of the door-boat a water chamber 2 m wide, into which the water intended to produce beaching is introduced; this water is supplied by the city water mains. The drainage valves placed at the bottom of this chamber are calculated so that raising takes place slowly enough.

Watertight tubes pass vertically through the air chamber to allow the escape of air that would be trapped below, on one side only, during the filling of the dock, which would tend to capsize the door-boat.

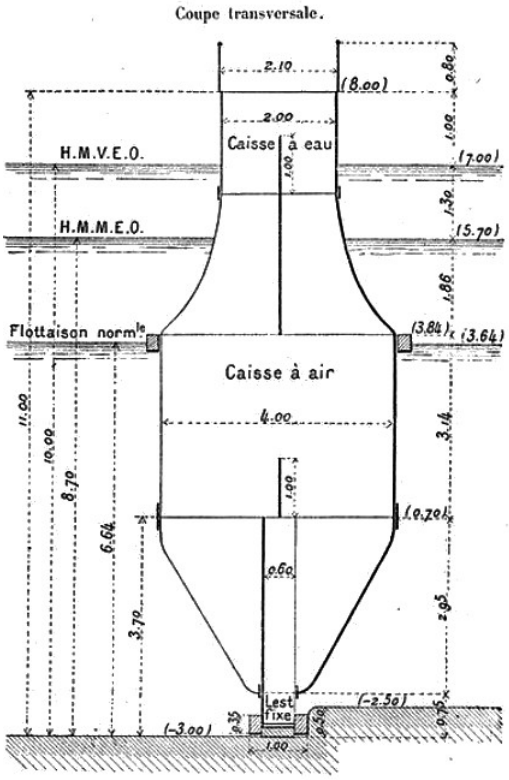


Fig. 612. — Calais.

Immersion can thus be carried out by opening the bottom valves with which the air chamber is provided; a central partition of sufficient height prevents sudden movements of water from one side to the other. After immersion, this water is drained into the dried dock, and the upper chamber is filled, the bottom of which is at the level of ordinary spring high tides. The stability of the door-boat remains assured, even if all the ballast is transferred to the upper chamber. The fixed ballast is placed on the keel.

The advantages presented by this type of door-boat are as follows: the double plating is reduced to a minimum, and the center of buoyancy being placed very high, the cast iron ballast is as small as possible; the ballast to be introduced to allow beaching is very small; moreover, in no case is there any risk of sudden raising of the door-boat before the dock is completely filled; finally, since the ballast can always flow out by itself, there is no need for a drainage pump.

From the examination of these various door-boats, it can be concluded that the type which, both for tideless ports and for tidal ports, best satisfies the most complete program is that due to Mr. de Coppier. This type, assuming a moderate door-boat width, combines the following conditions:

1° Require no pumping, except in the exceptional case common to all systems where the door-boat must be raised without the dock having been drained;

2° Reduce in this case to a minimum the quantity and height of water to be lifted by means of pumps or pulsometers;

3° Allow raising to begin only when deemed appropriate and by only temporarily increasing the draft of the door-boat, so as not to require it to be put back in place earlier than under ordinary circumstances;

4° Regulate the speed of emersion at will.

But if one considers that the second of these conditions has as its counterpart the provision in the air chamber of a water ballast tank with a capacity of 10 to 12 m^3, and that this tank can be eliminated by letting an equivalent quantity of water enter above the permanent ballast, which will occupy a better position from the stability point of view, as is done at Le Havre and Dunkirk, it will undoubtedly be considered that this construction simplification is desirable in ports where the docks are in almost continuous service.

On the other hand, when there is no reason to maintain a constant flotation, the watertight deck can also be eliminated, as its position slightly above the flotation ceases to be indispensable.

Thus, by sacrificing secondary advantages, but simplifying construction and maneuvering, a type of door-boat has recently been arrived at that closely resembles the Corrard system, except that the latter, corresponding to a tidal port where it is useful to maintain a normal flotation, limits the water ballast by a watertight deck which prevents its sudden displacement.

When, on the contrary, it is desired to vary the flotation and raise the door-boat only by an approximately constant height, despite variations in the basin level, it is advisable to have fixed ballast for the major part and to prevent sudden displacements of water by a few vertical partitions which constitute distinct tanks with corresponding bottom valves.

One can then regulate the introduction of water into the various parts, straighten the door-boat if it tends to incline one way or the other, and empty a compartment at will, to inspect and repaint it when the dock is drained.

All door-boats whose stability is ensured by the presence of liquid ballast in the lower part lose this stability when the ballast is exhausted while they are floating freely, and fall over on their side. By adding a few barrels of ballast to the upper part, one then succeeds in raising the keel, which allows repair and maintenance of the keel and gaskets. This facility is valuable in ports which have only one dry dock.

OPERATING CONDITIONS OF DOOR-BOATS

The operating conditions of door-boats are easily established, as shown by the following indications relating to a door-boat of the de Coppier type (fig. 613).

Let:

MN be the normal flotation of the door-boat;

XX be the trace on the vertical plane of the contact surface of the stem/stern posts against the rabbet;

A be the displacement of the left part of the hull mrp;

B be the displacement of the right part nrps;

δ be the displacement of the part mnn'm' between the flotation and the rebate deck;

V be the volume of the tanks filled with water to sink the door-boat;

u be the displacement of the descent wells;

u' be the displacement of the structure above the rebate deck.

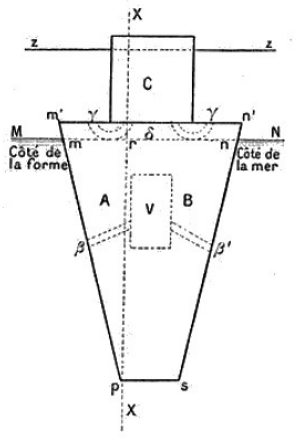


Fig. 613.

For the door-boat to sink by filling the tanks *V*, the weight of water introduced into the tanks must be greater than the increase in buoyancy due to the immersion of the upper part of the door-boat, i.e.:

$$V > \delta + u + u'$$

The door-boat will then bear on the bottom with a pressure P determined by the equation:

$$P = p\,[V - (\delta + u + u')]$$

where p is the weight of one cubic meter of sea water.

The pressure P generally varies from 3 to 10 t.

Since V must be greater than δ, it is advantageous to reduce the volume δ to decrease the quantity of water to be introduced into the door-boat and to speed up the maneuver. The height of the rebate deck above the flotation must therefore be small; it is most often only about ten centimeters; however, it must be given a certain value so that stability is not compromised by the few rolling movements that the door-boat may experience, which would cover the deck with water.

To raise the door-boat, the tanks V are emptied; the rise occurs when the emersive force is sufficient to overcome the adhesion of the door-boat to its rabbets (fig. 614).

Now the weight is equal to:

$$A + B + a + b\,,$$

where a and b are the weights of water contained in the upper compartment, to the left and right of XX, up to the level ZZ of the water in the basin.

The displacement is equal to:

$$A + B + \delta + u + u' + \left[\left(1 - \frac{x}{l}\right)a\right] + b\,,$$

if we denote by:

l the distance between the rebate deck and the water level in the basin;

x the difference in water level between the basin and the dock at which the rise will occur,

and if it is assumed that, above the rebate deck, the quantities of water contained in the upper compartment are proportional to the heights.

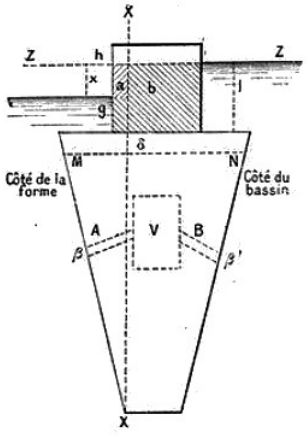


Fig. 614.

This expression for the displacement is not entirely exact, in the sense that the part relating to the volume of a corresponding to the height x, which receives no buoyancy from the water, should be subtracted from $u + u'$, but the error is very small.

The emersive force, which is the difference between displacement and weight, then has the expression:

$$\delta + u + u' - \frac{x}{l}\,a$$

Calling F the resistance produced by friction, we have:

$$F = \delta + u + u' - \frac{x}{l}\,a$$

If we know the force necessary to overcome the friction of the door-boat against the side wall, i.e., to produce detachment, this equation will give the value of x. The limit case being where $x = l$, for the door-boat to operate by itself, without needing to be detached using jacks, we must have:

$$\delta + u + u' \geqslant F .$$

Consequently, for a door-boat to be in good immersion and emersion conditions, its various elements must satisfy the two inequalities:

$$V \; > \; \delta + u + u' \; \geqslant F .$$

Detachment occurs for a level difference x, which is determined as indicated. This difference should not be too great, otherwise under the difference in pressures acting on the two faces of the door-boat, accidents could occur; but it is completely useless to bring it below 0.30 m to 0.35 m.

When detachment is effected, water enters the dock through the grooves; the level gradually equalizes. The door-boat has then risen by a height which is determined as follows (fig. 615).

Let YY be the new flotation and let y be the height by which the door-boat has risen, i.e., the distance between the plane of the new flotation and the water level maintained in the upper compartment.

The weight is equal to the buoyancy; the weight has the expression:

$$A + B + \pi$$

π being the weight of the water contained in the upper compartment.

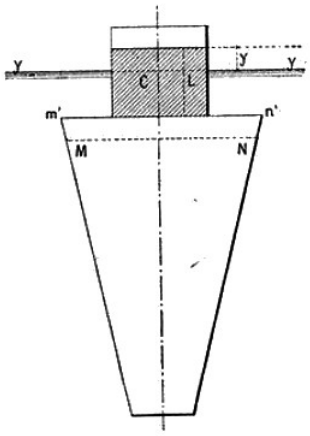


Fig. 615.

The buoyancy has the expression:

$A + B + \delta +$ *displacement of the part between level YY and the rebate deck.*

This displacement, assuming that in the upper compartment C the displacements are proportional to the heights, can be estimated by the expression:

$$\left(\pi + u + u'\right) \frac{l - y}{l}$$

the first factor being the displacement of the whole part up to sea level.

Therefore we have:

$$A + B + \pi = A + B + \delta + \left(\pi + u + u'\right) \frac{l - y}{l}$$

And consequently:

$$\frac{y}{l} (\pi + u + u') = \delta + u + u'$$

From which the value of y is deduced.

It is desirable that y be smaller than the height of the rabbet, so that the keel of the door-boat does not completely uncover the edge of the dock entrance and water does not enter it too quickly.

After this first rise, the valves of the upper compartment are opened, which then gradually empties; the door-boat comes to float on its normal flotation line *MN*.

Stability of Door-Boats

A floating body is in equilibrium whenever the weight of the body is equal to the weight of the volume of water displaced and the two forces are directed along the same vertical.

When the center of gravity is below the center of buoyancy, called in this case the center of displacement, the equilibrium is stable and the stability thus achieved is called *weight stability*.

Equilibrium remains stable even when the center of gravity, while being above the center of buoyancy, is below the metacenter. The metacenter is the center of curvature of the curve described by the center of buoyancy when the ship rotates about a horizontal axis without ceasing to float. The stability thus achieved is called f*orm stability*. In door-boats, weight stability is often not achievable.

The difficulty of achieving it stems from the great height of the door-boat above the flotation plane, which makes the door-boat very loaded in its upper parts. This circumstance is particularly encountered in door-boats intended to close dry docks opening into an outer harbor or a basin in which the variations in sea level are considerable.

But although weight stability is not indispensable, it is always advantageous to try to deviate from it as little as possible, i.e., to lower the center of gravity and consequently to reduce the weight of the structure above the flotation; this is one of the reasons why door-boats are often narrowed in their upper parts, above the watertight deck.

At least form stability must always be achieved; it is all the greater the lower the center of gravity is situated below the metacenter. Stability is measured by the value of this distance. Now we have:

$$\rho - r - a$$

where ρ is the distance from the metacenter to the center of gravity;

a is the distance from the center of gravity to the center of buoyancy;

r is the radius of curvature of the curve described by the center of buoyancy.

The value of r is equal to $\frac{I}{V}$, where

V is the immersed volume of the hull,

and I is the moment of inertia of the waterplane area with respect to the longitudinal axis of the door-boat.

Consequently:

$$\rho = \frac{I}{V} - a$$

Discussion of this formula highlights the various elements that affect stability:

1° r being always positive, ρ increases with the width of the door-boat at the waterline, and the increase grows in a certain proportion with the cube of this width.

2° With the same moment of inertia of the waterplane I, ρ will be greater the smaller the immersed volume V. It is therefore advantageous to narrow the hull below the waterline, when other considerations do not oppose the adoption of this solution.

3° To ensure a suitable value for ρ, a must be given as small a value as possible; it is sometimes even necessary to make a negative, i.e., to place the center of gravity below the center of buoyancy and thus return to weight stability. This is achieved by placing very heavy ballast in the lower part of the door-boat.

One then understands why a door-boat having a rebate deck necessarily loses its form stability as soon as the watertight deck disappears under water; indeed, I decreases in large proportion as soon as the rebate deck is submerged.

METHOD OF CONSTRUCTION

The tendency is to simplify the shapes of door-boats as much as possible and to abandon rounded shapes, reminiscent of those of ships, shapes which are not necessary for an apparatus that only has to perform slow movements over a short distance.

Curved shapes have the disadvantage of requiring forging work, cutting, false squaring and consequently significantly increase the construction cost. It is therefore advisable to choose for door-boats external shapes that reduce construction difficulties as much as possible; but it is no less necessary to adopt fairly smooth shapes, to avoid corners, complicated parts, conducive to mud deposits and difficult to keep in good clean condition, as well as protruding parts liable to shocks or collisions.

It is also important to take into account the influence of external shapes on the stability of the door-boats, which must be amply ensured, under penalty of being subject to maneuvering difficulties, the failure of which could have serious consequences.

It is useful to cement the bottoms of door-boats, as is done for ships, to prevent the keel from deteriorating rapidly under the influence of humidity or stagnant water that remains there.

The keel and the stem and stern posts, which transmit to the masonry all the pressure received by the door-boat, must be very solidly constructed and connected to

the rest of the structure; they are lined on both faces with wooden rubbing pieces on which the gasket is nailed. The keel must be about 0.10 m higher than the sill; a wooden sole is sometimes placed under the keel to protect it during beaching. Inspection and maintenance must be made easy at all points by giving the various compartments dimensions sufficient for workers to be able to access them easily. Manholes and shafts must be arranged to allow descent into the hold, even when the upper compartments are full of water.

Regarding the internal structure, the choice between a framework having as its main elements vertical uprights or horizontal crosspieces depends both on the cross-section of the entrance lock and on the type of door-boat.

If the side walls have a fairly large batter, the conditions are less favorable for the use of the vertical system; the horizontal system then has the advantage that the most heavily loaded crosspieces are the shortest. But because of the lower shapes of the door-boat, these have less height than those located above, it is advisable to relieve them by transferring part of the load onto the sill by means of a few vertical needles, also taking advantage of the resistance of the watertight decks when they are installed, or by making them coincide with vertical partitions.

Finally, when the vertical system is used with or without intermediate decks or crosspieces, it seems advantageous, instead of multiplying the needles too much to fix the plating directly, to establish several horizontal belts on which vertical members receiving the plating rest.

This distribution of the water load over a system of braced members, whose dimensions decrease as one passes from one direction to another, leads to a significant saving in weight and is eminently favorable to the rigidity of the door-boat.

It is possible to avoid galvanizing door-boats, as galvanizing has the disadvantage of sometimes modifying the texture of the metal and deforming the parts, especially when they are curved. On the other hand, the maintenance of door-boats can be carried out easily and alternately on each face, renewing the paint when the dock is drained; galvanizing is therefore less useful than for lock gates, at least one face of which, and generally both, remain almost constantly immersed.

In Dunkirk, the door-boats consist of approximately equidistant horizontal crosspieces, formed by a double line of belts connected by a lattice supporting vertical Z-shaped frames, to which the plating is fixed. The system is stiffened by five transverse partitions formed by a solid web with angle bars and rising to the crosspiece located at elevation (1.75 m); above, these partitions are continued by a lattice. The permanent ballast consists of cast iron pieces molded to match the shapes of the door-boat and to allow stowing that leaves no empty spaces. This precaution was taken to increase the density of the ballast, lower the center of gravity and improve stability.

In Marseille (*fig. 616*), the framework of the door-boats also consists of a series of braced horizontal beams, having the shape of equal resistance; these beams have a height equal to the width of the gates measured at the thickest part. The angle bars forming the flanges of these beams are of constant cross-section and are used without false squaring, which greatly simplifies labor and preserves all the strength of the

iron. However, it should be noted that the quantity of metal and ballast per square meter of bearing surface is slightly greater than in other gate systems; but this extra cost is largely compensated by the lower labor cost.

In the Toulon door-boats (*fig. 617*), the horizontal beams of the floats have unequal heights; the flange angle bars must then be sent to the forge to open the angle of those facing the rebate deck and to close the angle of those facing the keel. This arrangement considerably increases labor costs, and the forging work significantly impairs the strength of the metal. The door-boats of Saint-Nazaire, Lorient, Bordeaux and Cherbourg are also made up of a system of horizontal beams connected by vertical bracing and double plating.

In these various types, perhaps insufficient account has always been taken of the natural support offered by the sill, in order to transfer part of the pressures onto it. The lower part of Cherbourg door-boat 5, however, has been provided with powerful vertical ties, which relieve the frames.

Le Havre door-boats 1, 2 and 3 (*fig. 618*), on the contrary, consist of a series of vertical frames formed by Z-shaped angle bars, connected by three tiers of plate and angle bar crosspieces, or beams, then by floor timbers, the watertight deck and the upper deck. This system is very similar to the method of construction of ships.

The Calais door-boat (*fig. 619*) comprises three large horizontal crosspieces, two of which form the top and bottom of the air chamber, and which are solidly connected to each other by U-shaped irons arranged in a cross and by solid partitions. These two lower crosspieces are 4 m high, the third is only 2 m high. The lowest crosspiece is strongly connected to the stem and stern posts, so as to transmit under good conditions the pressure it supports to the grooves. Vertical frames spaced 0.51 m apart are attached below the lower crosspiece by strong gussets. The plating plates are 1.705 m wide, to reduce the number of joints to be made watertight and the caulking to be done.

In Le Havre door-boats 5 and 6 (*figs. 620* and *621*), the framework also consists of horizontal and vertical beams; the watertight deck and the upper footbridge support, together with the lower abutment sill, the entire water load. For this purpose, three vertical lattice beams have been arranged, to which the plating transmits part of the pressure; the rest of this pressure is transmitted to the rabbets of the side walls; the pressure is transmitted to these beams by horizontal belts on which the Z-shaped vertical members supporting the plating rest. Bracing is provided in the transverse direction by the lattice bars of the vertical beams, in the horizontal direction by St. Andrew's crosses, which are intended to reduce the span of the belts and increase their rigidity, finally in the longitudinal direction by the plating itself.

The pressure exerted on the part of the door-boat between the watertight deck and the upper deck is simply distributed to these beams by the vertical frames supporting the plating. This upper chamber is braced by means of vertical crosses placed in the same plane as the vertical beams of the lower compartment and horizontal crosses placed halfway between the beams.

The La Pallice door-boats have similar arrangements; they support a 2 m wide footbridge. The largest is 22.93 m long and 4 m wide (*fig. 622*); the framework consists

of four vertical lattice beams, a strongly constructed watertight deck towards the central part of the door-boat, and three intermediate horizontal belts, one between the watertight deck and the upper deck, the other two between the watertight deck and the keel; Z-shaped vertical frames transmit the pressure received by the plating to the horizontal belts.

In Bordeaux, the door-boat, recently built to replace the one previously in service, has an external shape similar to that of the previous door-boats. But the framework is significantly different (Pl. XIII); it includes at the upper part a horizontal lattice beam having the entire length of the door-boat, 22.75 m, and a width of 4 m, except at the stem and stern where this width is reduced to 0.80 m. Eleven vertical lattice beams, 9.15 m high, distribute the pressure on the upper beam and on the keel. A watertight deck is established at the height of normal flotation; it is supported by horizontal crosspieces forming part of the lattice of the eleven vertical beams. The plating on the flanges of the vertical beams is stiffened by Z-shaped horizontal frames. The upper part supports a carriageway 2.50 m wide and two 0.80 m footwalks.

The door-boats in use in England are generally of less simple construction than the types just described; they include a greater number of watertight compartments.

The Blackwall door-boat (*fig. 623*) has a rectangular section without a keel, contact being established as for lock gates between the sill and the side of the door-boat; it is 20.50 m long, 3.05 m wide and 8.78 m high. Fixed concrete ballast is placed at the lower part; above is the air chamber, separated by a watertight deck from the upper compartment which receives the water ballast necessary for beaching.

The Barry Dock door-boat (*fig. 624*) has, on one side, a rounded shape similar to that of a boat and, on the other, a vertical wall over its entire height; this arrangement is intended to allow it to be placed in a recess in the quay wall, when not in service, without any of its parts projecting from the wall facing. This door-boat has a fairly large number of watertight compartments formed by two horizontal decks and two vertical partitions. This arrangement is not to be imitated; it does not allow the door-boat to be turned over, so as to place each of its faces successively in the dock for inspection and repainting.

The Bute Dock door-boat (*fig. 625*) is much wider than all the door-boats already described; it is 18.30 m long, 7.93 m wide at the lower part and 3.96 m wide at the upper part. It is divided by a watertight deck and various partitions into sixteen compartments communicating with each other through orifices fitted with valves. A steam pump placed on the watertight deck makes it possible, if necessary, to empty part of the water ballast. A cast iron ballast of 120 t is moreover placed at the lower part near the keel; this ballast, together with the weight of the door-boat itself, which is 125 t, is calculated so as to allow the door-boat to float when the water is at the lowest level at which it needs to be raised.

The door-boat of the North German Lloyd dock at Bremerhaven (*fig. 626*) has a float placed in the intermediate part, below the water level in the basin; in the lower and upper parts, there is only a plate placed in the axis of the door-boat.

The door-boat of the new Boston dock in the United States has a total length of 31.80 m (*fig. 627*); its width at the thickest part reaches 6.70 m and its height is 11.10

m. Concrete ballast is placed at the lower part to ensure it a normal draft of 5.65 m. Two intermediate watertight decks divide the door-boat into three compartments. Immersion is achieved by introducing water through three 0.55 m diameter valves. Raising is carried out by pumping out the water thus introduced with a centrifugal pump delivering 13,630 l per minute; this pump is installed in the upper compartment, together with the steam engine that drives it.

The following table gives the dimensions, weights and prices of a certain number of door-boats.

PORTS	WET DOCKS.	LENGTHS		HEIGHTS	SURFACES	WEIGHT			PRICE		OBSERVATIONS
						without ballast.		with ballast.			
		in the lead.	from the keel.			total.	per meter².		total.	per meter².	
		m.	m.	m.	m²	kg.	kg.	kg.	fr.	fr.	
Dunkerque	2 and 3	20.1	14.234	8.8	151	87,000	567	153,000	60,000	397	Cart track.
id.	4	28.05	21.234	10.3	253	183,000	723	281,000	114,000	451	id.
Calais	4	22.1	22.1	11	243	249,000	1,025	273,000	177,240	729	
Le Havre	3	16.94	14.7	8.1	132.89	111,707	841	172,366	"	"	Cart track.
id.	4	31.08	29.04	11.15	335.17	277,690	829	664,150	185,512	554	id.
id.	5	21.08	18.075	11	215.35	202,756	942	415,357	245,968	659	id.
id.	6	17.08	13.86	10.15	157.02	144,458	920	263,179			
Cherbourg	5	30.6	26	43.8	390.54	375,000	960	540,000	356,000	912	id.
Saint-Nazaire	1	26	21	10.4	254.9	199,172	781	408,152	246,261	966	
id.	3	19	15	10.4	185.2	148,628	803	264,413	165,475	893	
La Pallice	1	22.93	22.93	11.203	256.88	202,732	789	380,412	157,490	614	
id.	2	14.93	14.93	11.203	152.33	118,194	776	204,444	94,301	619	
Rochefort	2	15.82	14.023	6.7	91.1	70,000	769	81,000	47,930	526	
Bordeaux	2	22.75	22.75	10.6	241.15	107,328	446	450,596	152,623	513	Cart track.
Marseille	1-2	25.2	13.5	9.5	183.825	109,200	594	188,700	"	"	
id.	3-4	16.86	11.06	8.5	118.66	70,900	598	128,500	"	"	
id.	5-6	16.86	11.06	8.5	118.66	70,800	597	128,500	65,000	548	
Toulon	Missiessy.	29.742	25.75	11.975	332.258	273,090	829	424,884	226,400	681	
Alger.	Big.	27.36	22.15	10.68	262.25	208,767	796	404,040	168,800	643	
id.	Small.	20.8	16.7	8.25	153.65	80,587	524	145,360	96,100	625	

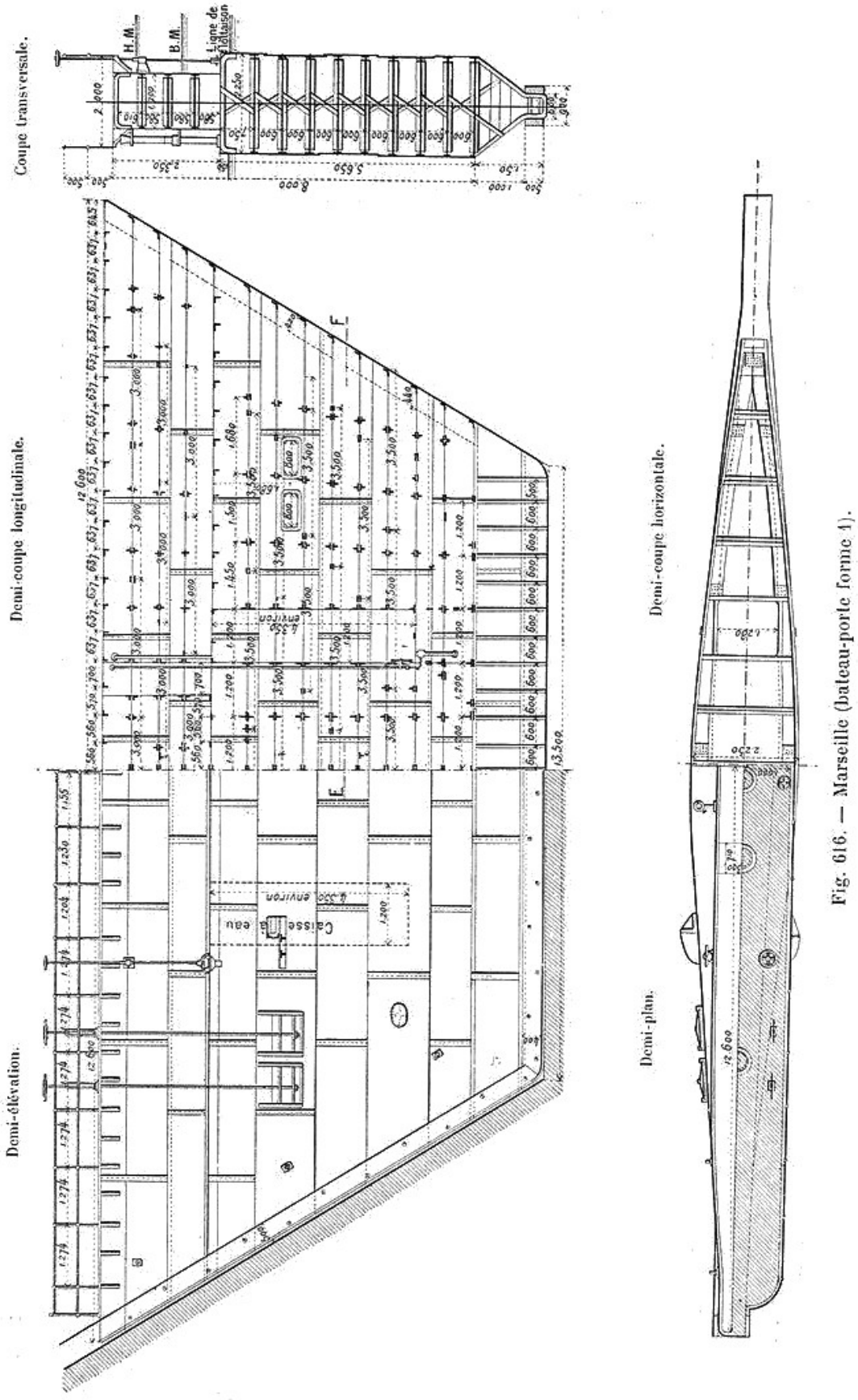


Fig. 616. — Marseille (bateau-porte forme 1).

Fig. 616 - Marseille (door-boat of wet dock 1)

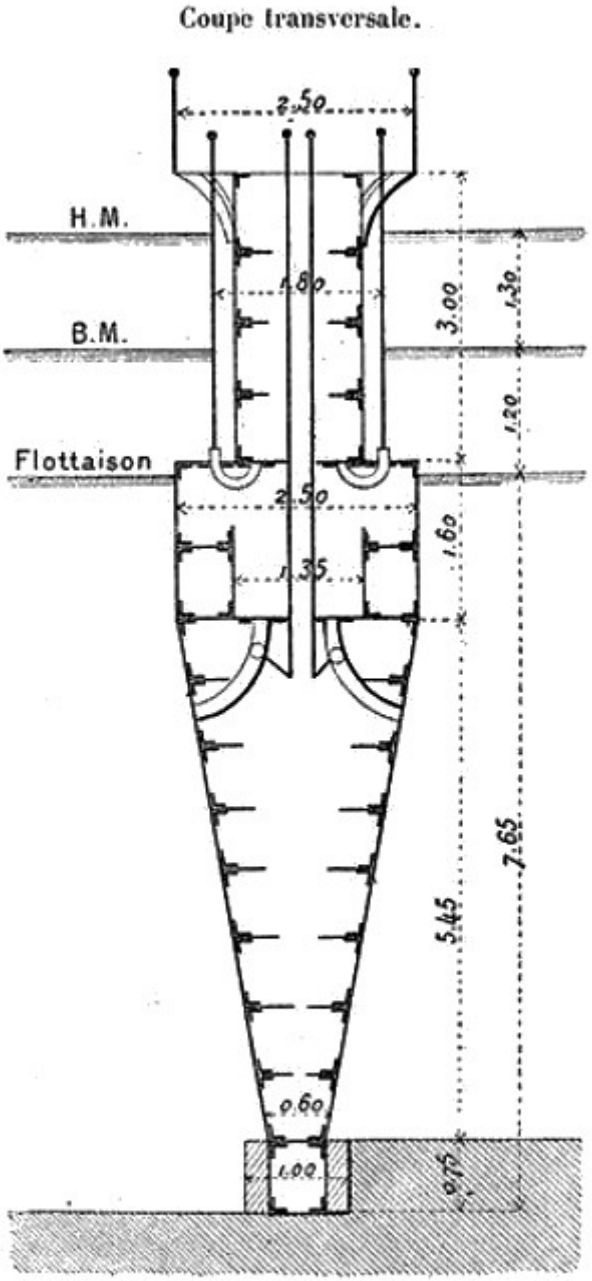


Fig. 617. — Toulon (bateau-porte de la forme 1 de Castigneau).

Fig. 617 — Toulon (door-boat of Castigneau's wet dock 1)

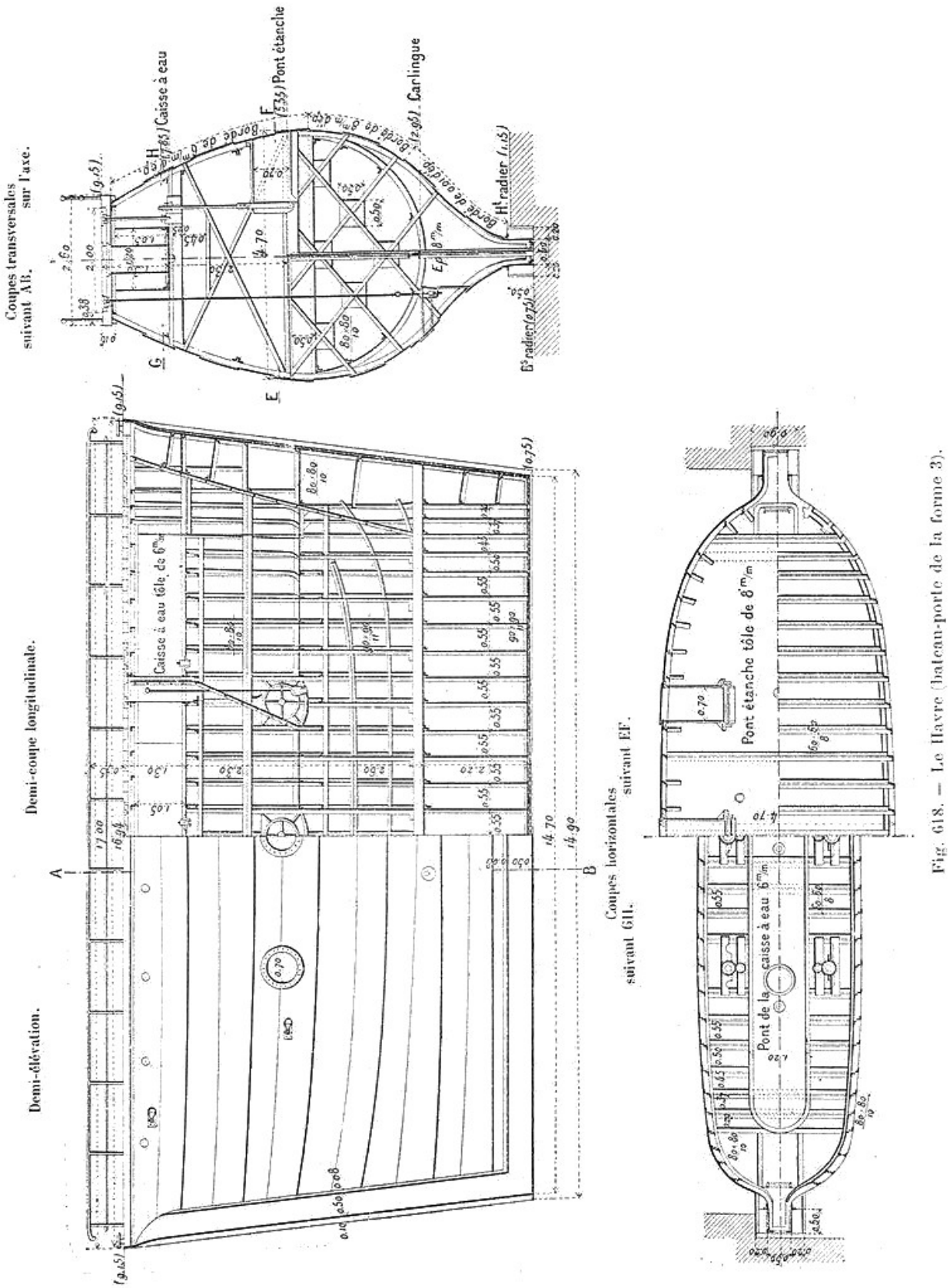


Fig. 618. — Le Hâvre (bateau-porte de la forme 3).

Fig. 618 — Le Hâvre (door-boat of wet dock 3)

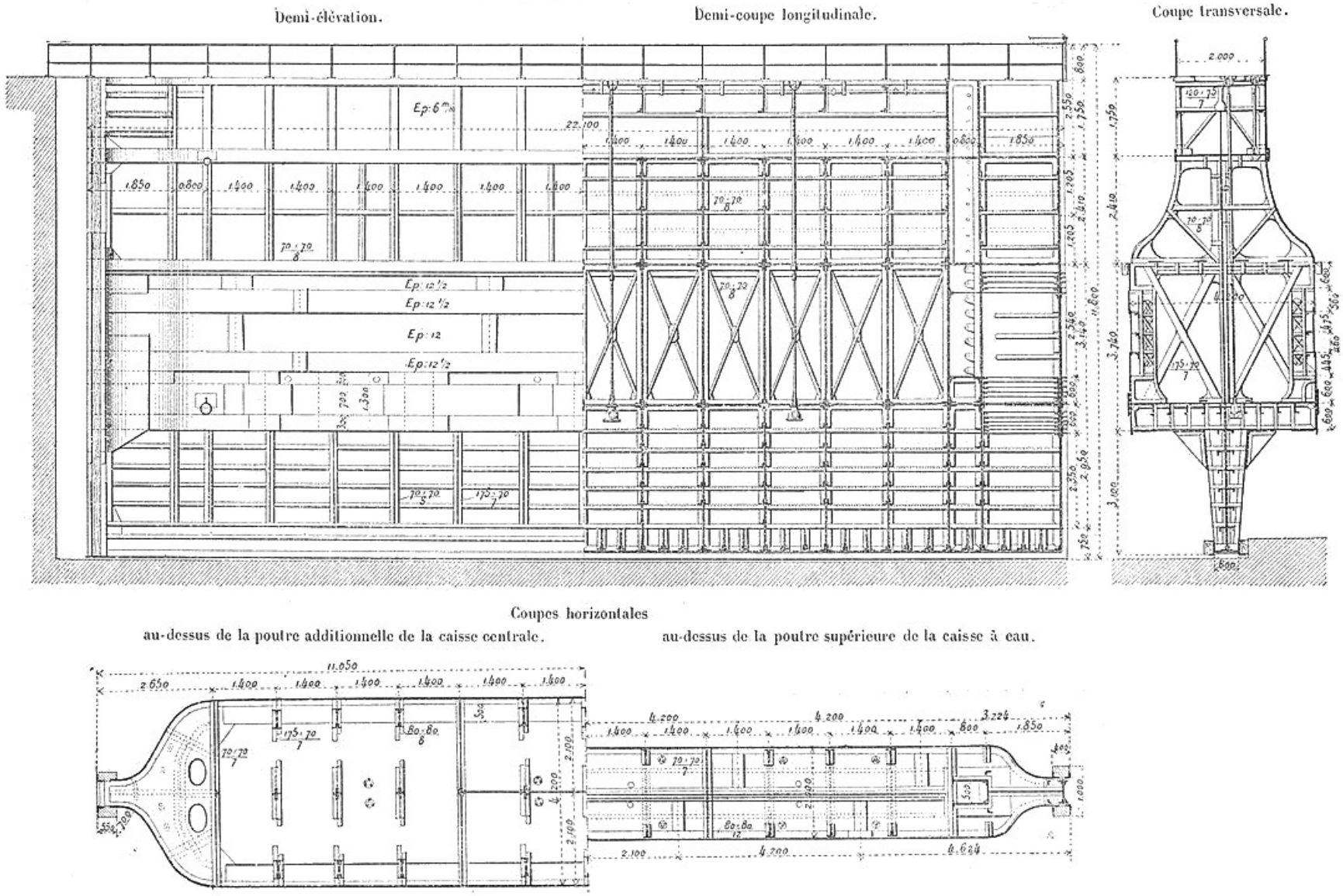


Fig. 619. — Calais.

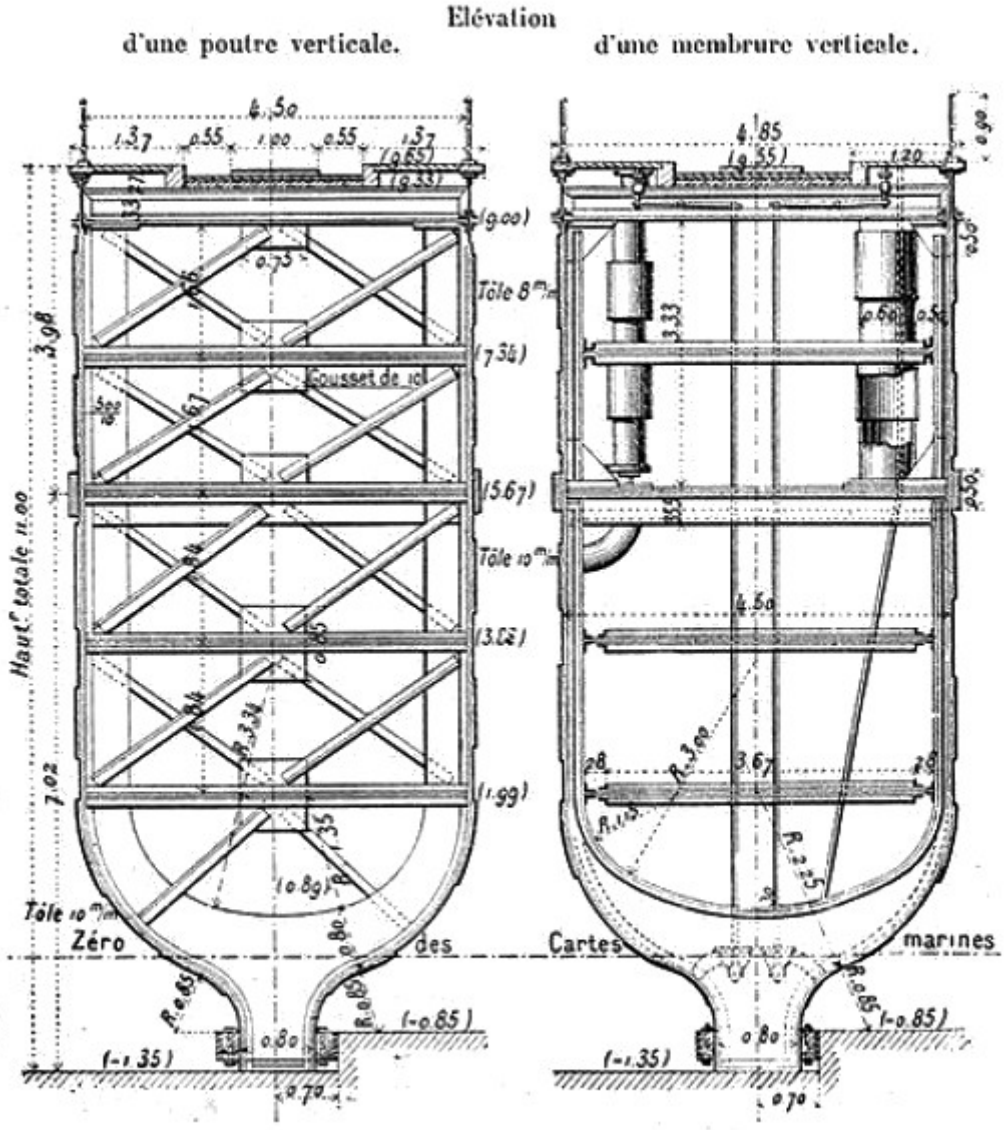


Fig. 620. — Le Havre (bateau-porte de la forme 5).

Fig. 620 — Le Hâvre (door-boat of wet dock 5)

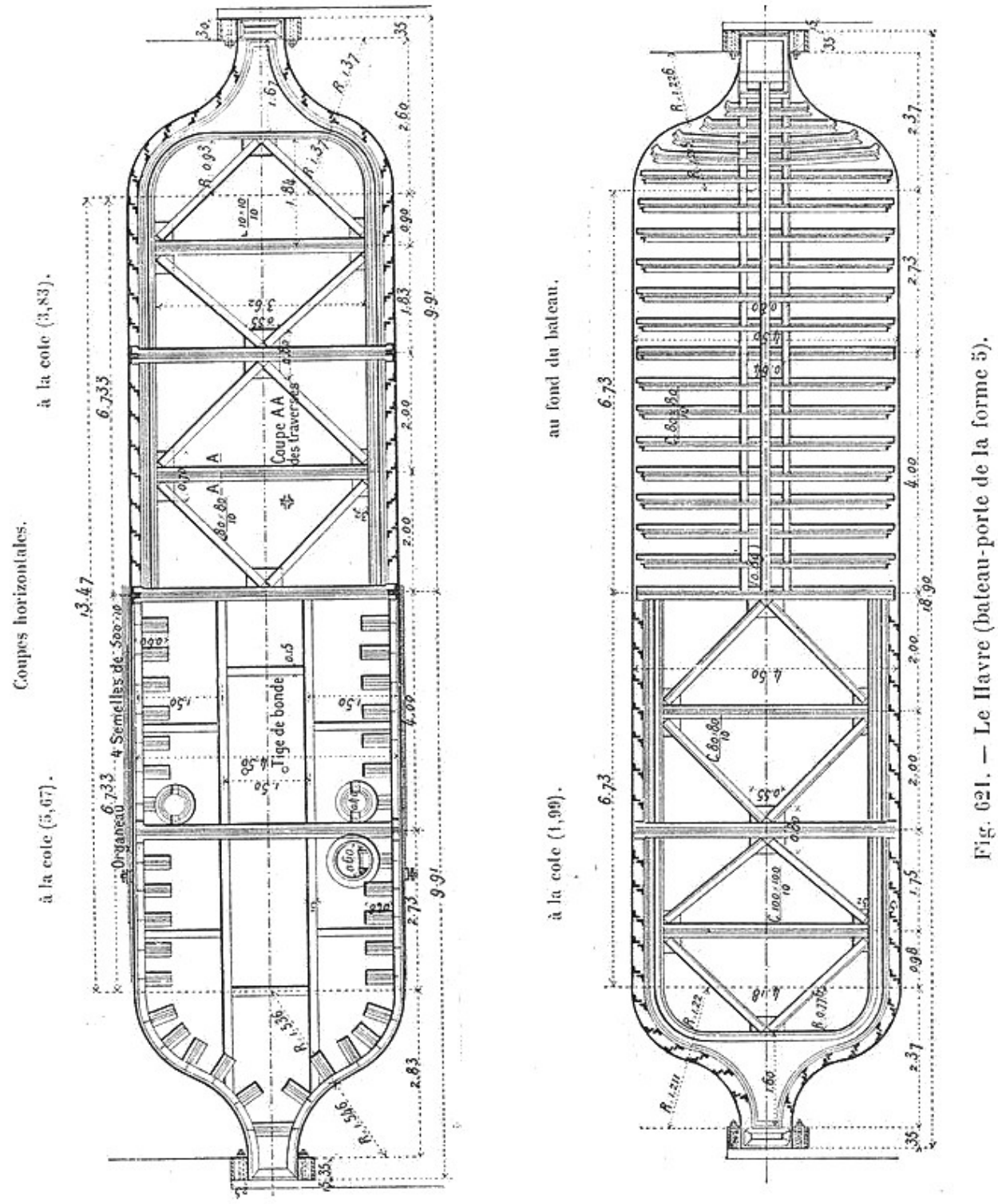


Fig. 621. — Le Havre (bateau-porte de la forme 5).

Fig. 621 — Le Hâvre (door-boat of wet dock 5)

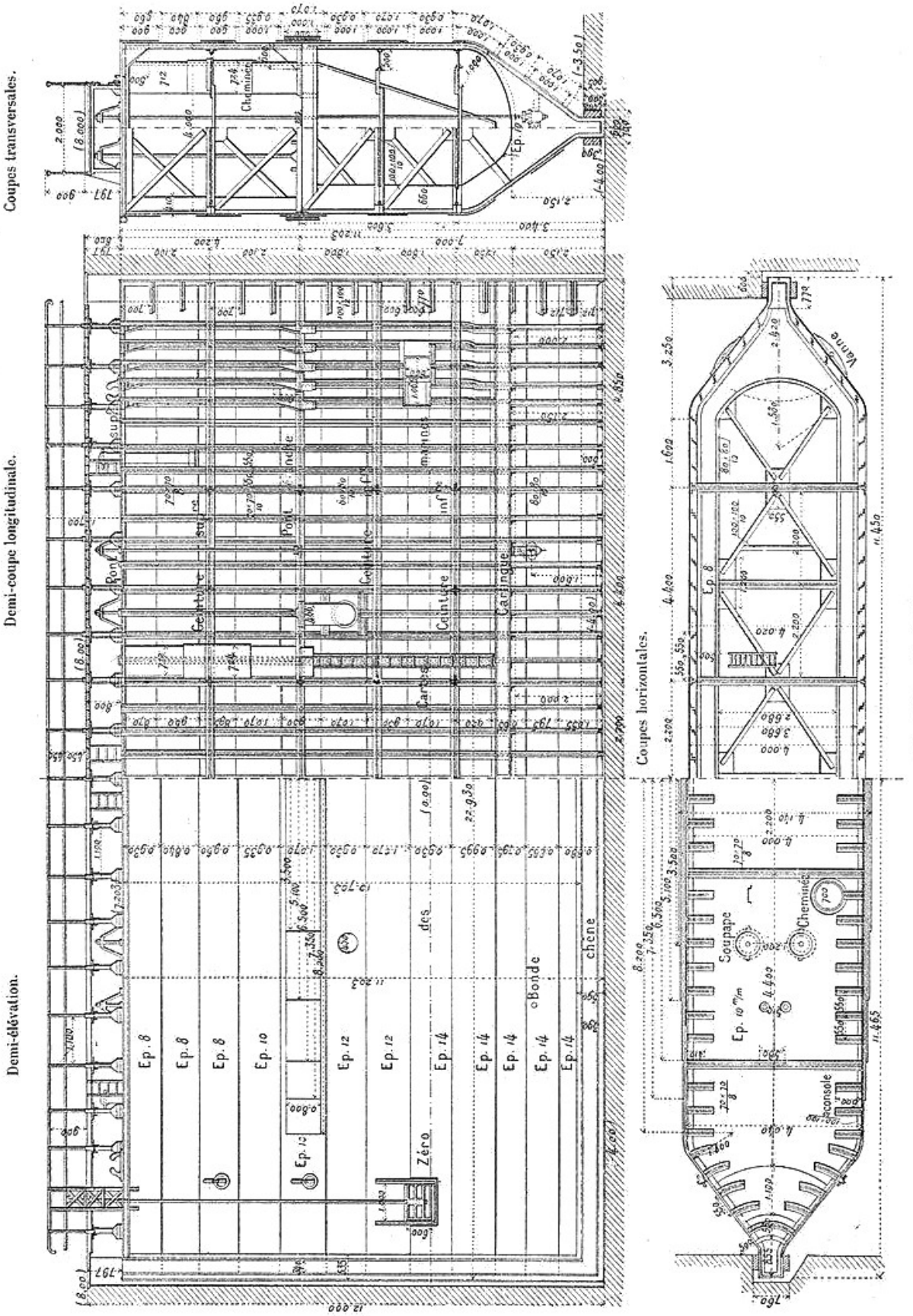


Fig. 622 — La Palisse

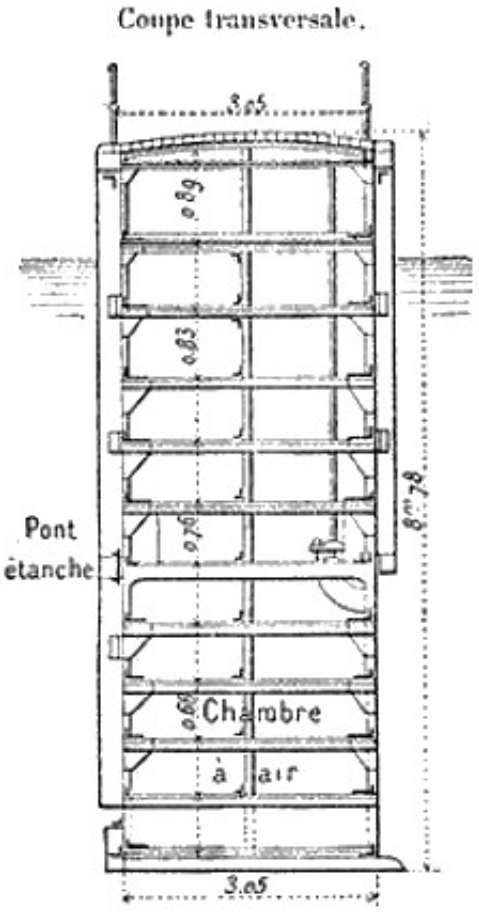


Fig. 623. — Blackwall.

Fig. 623 — Blackwall

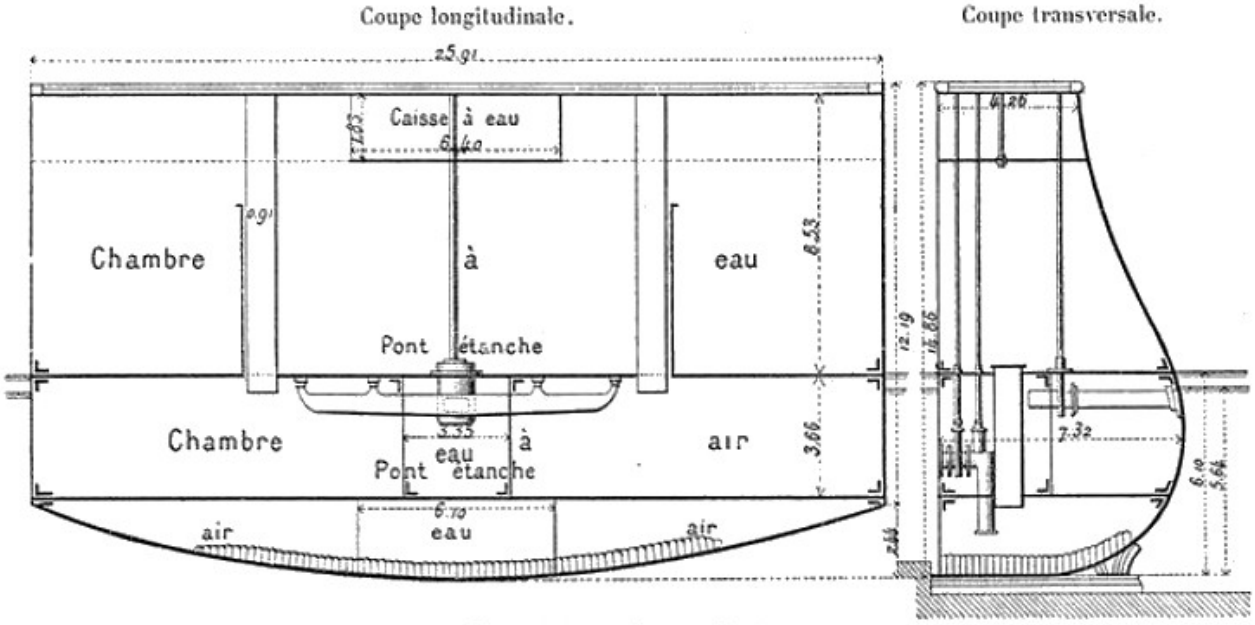


Fig. 624. — Barry dock.

Fig. 624 — Barry dock

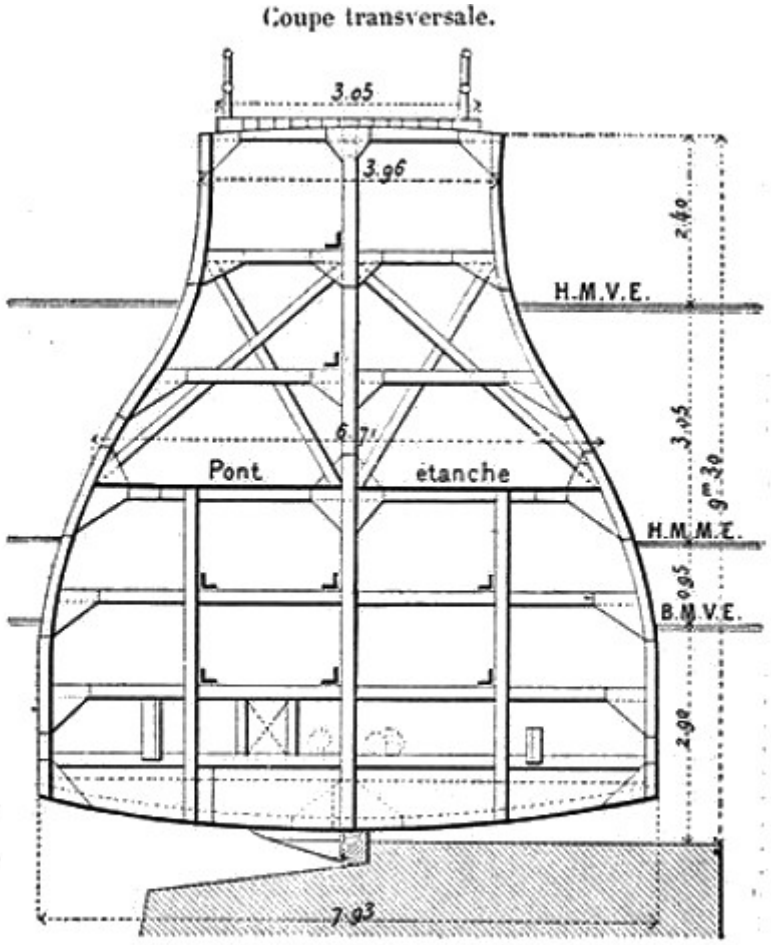


Fig. 625. — Bute dock.

Fig. 625 — Bute dock

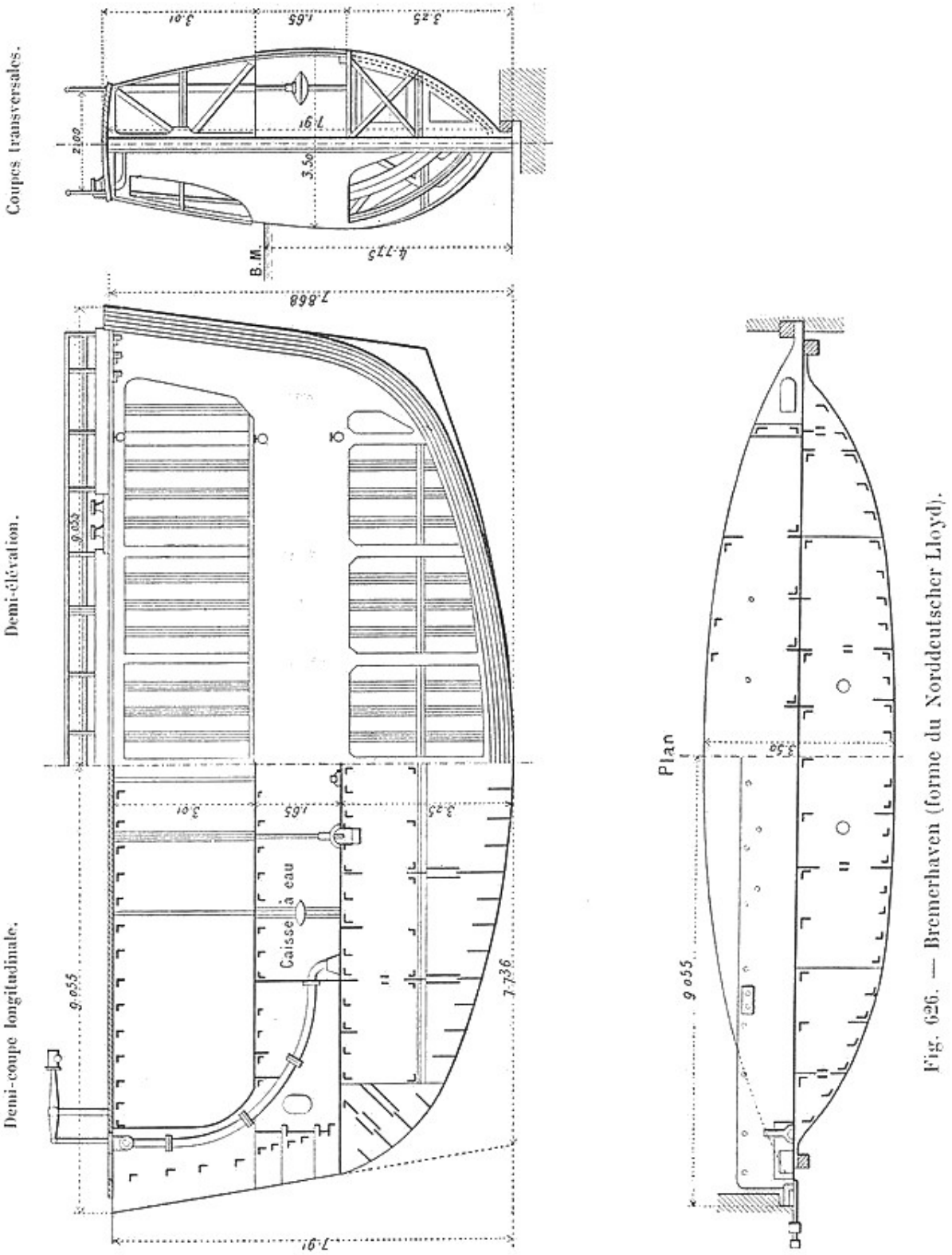


Fig. 626. — Bremerhaven (forme du Norddeutscher Lloyd).

Fig. 626 — Bremerhaven (Norddeutscher Lloyd's wet dock)

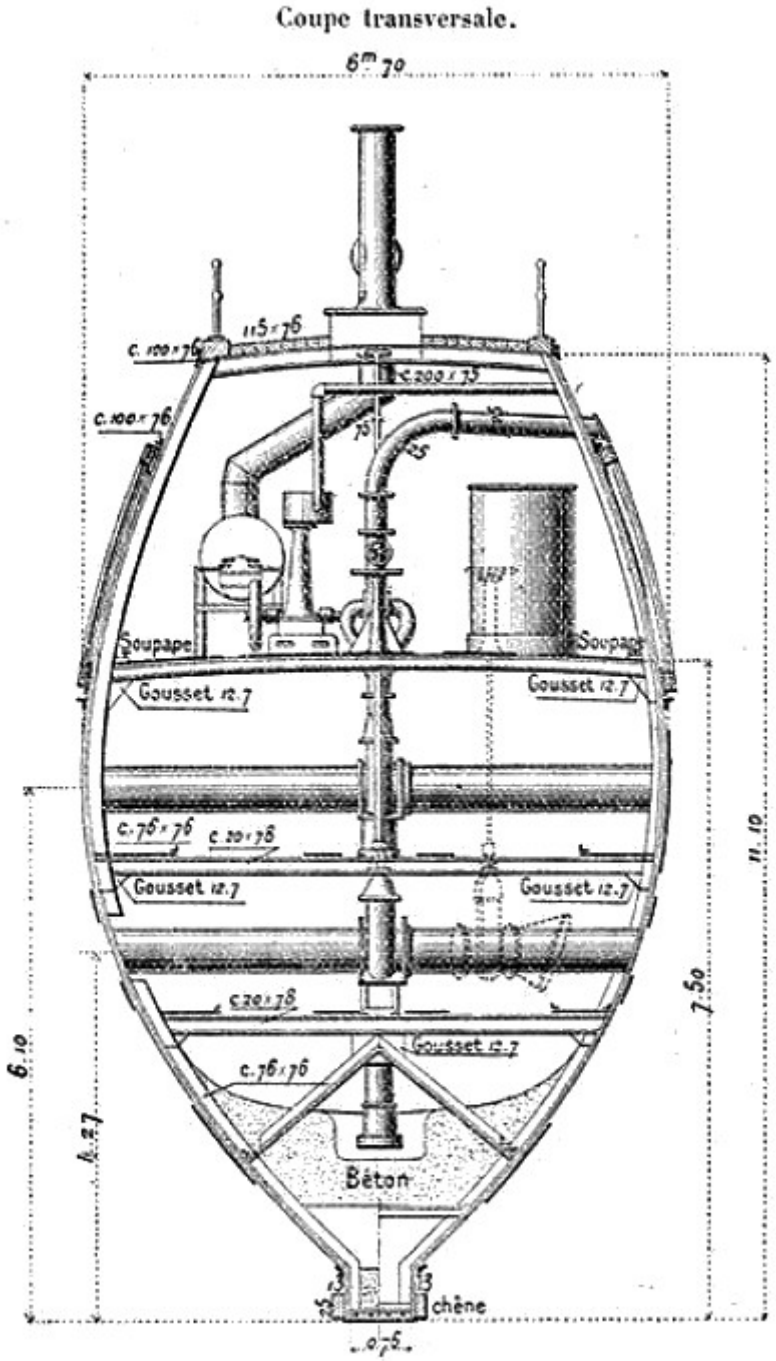


Fig. 627. — Boston.

Fig. 627 — Boston